APPLIED GEOPHYSICS AND THE DETECTION OF BURIED MUNITIONS

by

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ABSTRACT: Buried military munitions, such as bombs, artillery projectiles, rockets and landmines can present serious safety hazards. Geophysical investigations are often used to detect such munitions so that they can be safely recovered and destroyed. However, different geophysical methods each have particular capabilities and limitations. Magnetometers and gradiometers are well suited to detecting ferrous munitions to depths of two or three meters. However, they cannot detect non-ferrous munitions. Frequency domain conductivity meters are the best tools for detecting landmines containing very little metal; however, they are capable of detecting individual objects only to a depth of a few centimeters. Time domain conductivity meters can detect both ferrous and non-ferrous munitions and are effective to depths of only one or two meters. However they can be adversely affected by shallow groundwater. Ground-penetrating radar can be an effective tool for detecting munitions in sandy soils; however it is ineffective in clayey soils. In addition, Huntsville Center is developing geophysical data management and analysis software called the Ordnance and Explosives Knowledge Base (OE-KB) to improve the munition detection and recognition capabilities of geophysical investigations. However, even using best available hardware and software combinations, geophysical investigations to locate and identify buried munitions are seldom 100 percent successful and it is important to convey this limitation to all involved stakeholders.

INTRODUCTION

Buried munitions are a serious hazard at many locations both within the United States and overseas. Geophysical investigations are widely used to locate such munitions so they can be safely identified, recovered and destroyed. However, no single munition locator is effective for all types of munitions and in all locations. The purpose of this paper is to describe the main types of geophysical instruments currently in common use as munition detectors, to describe their uses and limitations, and summarize how the data from those instruments can be analyzed to facilitate ordnance detection.

There are many geophysical and remote sensing techniques beyond those mentioned in this paper that have application to the detection of buried, surface, or underwater munitions. However, this paper summarizes the methods most commonly used and having widest application.

BACKGROUND

With the invention of durable, modern fuzed munitions around 150 years ago, a long-term munition safety hazard was created at battlefields and training areas worldwide. That hazard remains long after the soldiers have left. In the United States there are still occasional accidents involving munitions fired during the Civil War (1861-1865). In Europe, accidents involving forgotten munitions are much more common as a result of the two world wars during this century. In France, 630 *demineurs* (para-military explosive ordnance disposal specialists) have been killed since 1946. On the civilian side, 36 French farmers died in 1991 alone when their machinery struck unexploded shells. Worldwide, a subset of munitions-- landmines, is a particular problem. According to the United Nations 110 million mines are buried in 64 countries, most of them unmarked. About 24,000 civilians are killed or maimed by those devices every year. Obviously, the detection and identification of buried munitions warrants a high priority in areas they exist.

EOD Operations in Kuwait

DETECTING BURIED MUNITIONS

Evolution of Ordnance Detectors

Military organizations first began fielding devices designed to locate buried munitions, particularly ferrous landmines, shortly before World War II. The first mine detectors generally operated on the principle of simple

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **AUG 1996**	2. REPORT TYPE	3. DATES COVERED **00-00-1996 to 00-00-1996**
4. TITLE AND SUBTITLE **Applied Geophysics and the Detection of Buried Munitions**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **U.S. Army Corps of Engineers,Army Engineering and Suuport Center, Huntsville,PO Box 1600,Huntsville,AL,35807-4301**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES **See also ADM000767. Proceedings of the Twenty-Seventh DoD Explosives Safety Seminar Held in Las Vegas, NV on 22-26 August 1996.**		
14. ABSTRACT **see report**		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

magnetometry. As a counter-measure, manufacturers began to construct mines containing little or no ferrous metal. Therefore, designers and manufacturers of mine detectors began to use different detection technologies. By the end of World War II conductivity meters were in common use.

GIs Searching for Mines in Normandy, 1944

Today, the best military mine/munition detectors still typically use one of the two technologies, depending on whether ferrous or non-ferrous buried munitions are being sought. When ferrous targets such as typical bombs and artillery projectiles are the objects of the search, then *magnetometers* (or *gradiometers*) are used. When non-ferrous targets such as many rockets, submunitions and landmines are objects of the search, then *conductivity meters* are better tools.

Most all successful military munition detectors use some variation of those two technologies to locate the relatively small, shallow objects of their search. However, the current generation of plastic anti-personnel mines remains extremely difficult to detect with any available equipment even under the best of circumstances.

GI Searching for Mines in Bosnia, 1996-Mine detection capabilities and equipment available to soldiers in the field have changed little in 50 years. Note the probe rod in this soldier's right hand.

Magnetometers and Gradiometers

Magnetometers were one of the first tools used for locating buried munitions and remain one of the best. Most bombs and gun shells contain a ferrous metal such as iron that cause a disturbance in the earth's geomagnetic field. As buried ferrous munitions are illuminated by the earth's primary magnetic field, a secondary magnetic field results which magnetometers detect. Magnetometers must be sensitive enough to measure the weaker secondary magnetic field caused by a buried munition superimposed on the much larger natural geomagnetic background. Some magnetometers use two magnetic sensors configured to measure the slope (difference over a fixed distance) of the magnetic field, rather than the absolute magnetic field, and are called *gradiometers*.

Currently, three types of magnetometers and gradiometers are most often used to detect buried munitions:

<u>Fluxgate Magnetometers</u>

A fluxgate magnetometer measures the magnitude and direction of the magnetic field. They are inexpensive, reliable, rugged, and have low energy consumption. Fluxgate magnetometers have long been a standard tool of EOD teams and are best used for rapid investigation by foot. For a quick, inexpensive field survey of a site

containing ferrous munitions they are hard to beat. Fluxgate magnetometers can detect single "munition-size" items (for purposes of this discussion, a cylindrical object varying in size from a beer can to a large loaf of bread) to a depth of 2 to 3 meters. However, they also are sensitive to small fragments and do not always discriminate well between small, shallow fragments and deeper, larger intact munitions. Most fluxgate magnetometers provide analog, rather than digital, output that makes it difficult to apply computer enhancement techniques.

Examples of commercial fluxgate magnetometers and gradiometers commonly used to detect buried munitions include, but are not limited to:

- Applied Physics Systems APS428C
- Applied Physics Systems APS520/520A
- Foerster Mark 26
- Schonstedt GA-52C
- Schonstedt GA-72V

Proton Precession Magnetometers

The proton precession magnetometer is based on the principle that magnetic fields can be inferred by measuring the movement of protons in a liquid such as water, kerosene or other hydrocarbon. When these protons are polarized and subjected to an ambient magnetic field, the frequency of precession will deviate from their natural frequency in proportion to the strength of the ambient field. This type of magnetometer is more sensitive than a fluxgate magnetometer. However, it is especially susceptible to noise from nearby power sources. Also, the quality of the data collected by a proton precession magnetometer is dependent upon the time spent collecting each data sample. As a result, they are slower to use than fluxgate magnetometers. Proton precession magnetometers can typically detect single "munition size" items to a depth of 2 or 3 meters.

Examples of commercial proton precession magnetometers and gradiometers commonly used to detect buried munitions include, but are not limited to:

- GEM GSM 19
- Geometrics 856AX/856AGX
- Scintrex WALKMAG/ENVIMAG

Optically Pumped Atomic Magnetometers

Optically Pumped Atomic Magnetometers (also called *atomic magnetometers* or *cesium vapor magnetometers*) operate similarly to proton precession magnetometers except that the proton is replaced by an atom of a specific gas vapor, such as cesium or potassium. However atomic magnetometers are more sensitive and have faster sampling rates than proton precession magnetometers. Atomic magnetometers can typically detect single "munition size" items to a depth of 2 or 3 meters. Although atomic magnetometers are more expensive to purchase than the other two types of magnetometers their high sensitivity, speed of operation and high quality digital signal output make them a good choice for situations where data fusion or digital post-processing is desired.

Examples of commercial optically pumped atomic magnetometers and gradiometers commonly used to detect buried munitions include, but are not limited to:

- Australian Defense Industries TM-4
- GEM GSMP-20
- GeoCenters STOLS
- GeoCenters MGSS
- Geometrics 822/833/858/Mk22
- Scintrex SMARTMAG

Since magnetometers and gradiometers detect signals, but generate none of their own, they are "passive" devices. Some other types of instruments generate signals and are called "active" devices. This is important because some munitions may be sensitive to radio frequencies. Some "active" geophysical instruments might cause those munitions to detonate.

Atomic Magnetometry

Conductivity Meters

Conductivity meters are electromagnetic induction tools that, like magnetometers, are used extensively to detect buried munitions. Conductivity meters have an advantage over magnetometers in that they are not limited to detecting ferrous items. They are also useful in detecting non-ferrous metallic items. When a metallic object is subjected to a varying magnetic field,

eddy currents are induced within the object. Conductivity meters detect buried munitions by measuring the secondary magnetic field produced by these eddy currents. The performance of conductivity meters is seriously degraded in areas underlain by shallow, mineralized groundwater. Since conductivity meters generate an electronic signal they are "active" devices. There are basically two types of conductivity meters:

Frequency Domain Conductivity Meters

Frequency domain conductivity meters produce electromagnetic waves that pass through the subsurface, causing eddy currents to form. The intensity and phase of those eddy currents is a function of ground conductivity. Buried debris and/or disturbed soil have conductivities different from the surrounding natural soil. It is those conductivity differences that frequency domain conductivity meters detect.

Frequency domain instruments are useful for detecting large buried caches of munitions, detecting disturbed earth associated with pits and trenches, and are the best geophysical tool available for detecting very small, very close objects such as the metal firing pins in plastic land mines buried just beneath the ground surface. However, since the resolution ability decreases dramatically with depth, frequency domain conductivity meters are not optimum for detecting individual, deeply buried munitions. Most commercial coin detectors are frequency domain conductivity meters.

Frequency domain conductivity meters commonly used to detect buried munitions include, but are not limited to:

- Geonics EM-31
- Geonics EM-38
- Schiebel AN/PSS 11&12

Time Domain Conductivity Meters

Time domain conductivity meters produce and measure an electromagnetic wave similar to that of frequency domain systems. A major difference is in the system waveforms used. Typically, a half-duty cycle waveform is used, and measurements made during the time the transmitter is off. The instrument locates metal by inducing a current in the ground and observing its decay with time. The detector portion of the instrument is tuned to sense only a specific portion of the response curve, which greatly reduces noise and improves signal detection for certain buried objects.

Time domain conductivity meters provide a good compromise between precision and speed. Such instruments also provide a capability to locate all types of metallic munitions. Generally they overlook small items such as nails or small munitions fragments but will see typical intact munitions to a depth of 1 or 2 meters.

Examples of commercial time-domain conductivity meters commonly used to detect buried munitions include, but are not limited to:

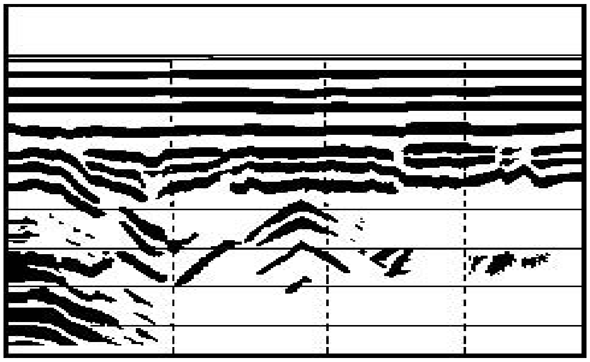
- Geonics EM-61

Time Domain Conductivity Meter

Ground Penetrating Radar (GPR)

Ground penetrating radar is another geophysical method used for subsurface detection of munitions. Like conductivity meters, they are "active" devices. A surface antenna produces a short pulse of microwave-frequency electromagnetic energy which is transmitted into the ground. As the transmitted signal travels through the subsurface some of the signal strikes "targets" such as buried munitions or stratigraphic changes, and is reflected back to the antenna. The depth of penetration of GPR is highly dependent on subsurface conditions. GPR can be effective to many meters in dry, clean sand, but is completely ineffective in saturated clays. Even small amounts of clay minerals in the subsurface greatly degrade GPR's effectiveness. GPR is slow to use and the signal is usually difficult to interpret. Under optimum conditions, GPR can be used to detect individual buried munitions several meters deep. However, such optimum conditions seldom occur.

GPR is normally more useful for detecting burial pits and trenches rather than individual items.



Typical GPR Output

Summary of Detection Capabilities

Detection capabilities of individual geophysical instruments vary because of a number of factors including the composition, size, and orientation of the particular munition; subsurface geological materials and conditions; natural and man-made electrical interference; and the specific investigation procedures used in the field. Even the general location of the site on the earth's surface can affect the success of certain geophysical methods.

In general, the larger the object, the deeper it can be detected. However, it is not possible to say that a particular instrument will always detect a particular item at a specific depth. Also, the capabilities of different geophysical instruments have not been well "benchmarked" for given munitions at specific depths. Manufacturers have done extensive in-house testing, but release of the actual data has been quite limited. Given the opportunities for misunderstanding, misapplication or misuse of such benchmark data, it is hardly surprising that it has not been released. However, some general detection capabilities of different types of geophysical instruments are shown below:

- Magnetometers and gradiometers detect only ferrous munitions and are effective to depths of 2 or 3 meters.

- Time domain conductivity meters can detect ferrous and non-ferrous metallic munitions to depths of 1 or 2 meters. Their performance can be degraded by shallow groundwater conditions. They are not effective for locating very shallow, very small metallic masses such as land mine firing pins.

- Frequency domain conductivity meters are the best tool for detecting land-mines containing little or no ferrous metal, but are effective to only a few centimeters. Other kinds of frequency domain conductivity meters are useful for detecting burial pits and trenches, but are not an optimum means of detecting single buried munitions.

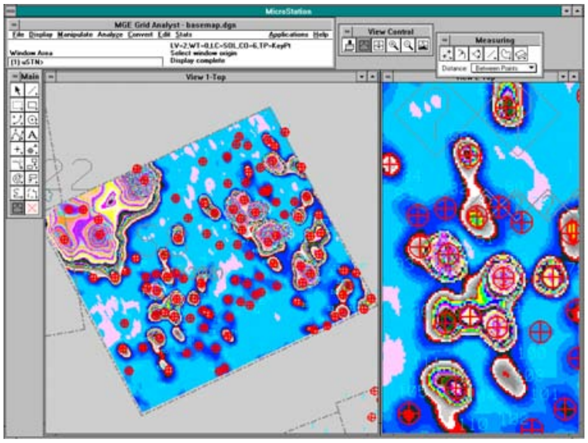
- Ground penetrating radar capabilities are extremely variable. GPR can detect individual munitions to a depth of several meters in dry, sandy conditions. However, application of GPR should be viewed with skepticism if wet, clayey subsurface conditions are expected.

ORDNANCE AND EXPLOSIVES KNOWLEDGE BASE

Computer-based evaluation is an important tool for interpreting geophysical data. Tests indicate that field operators visually or aurally evaluating analog or digital output generated directly by the geophysical instrument (lights, gauges, and tones) are not nearly as effective as a computer-based evaluation of digital data in an office environment.

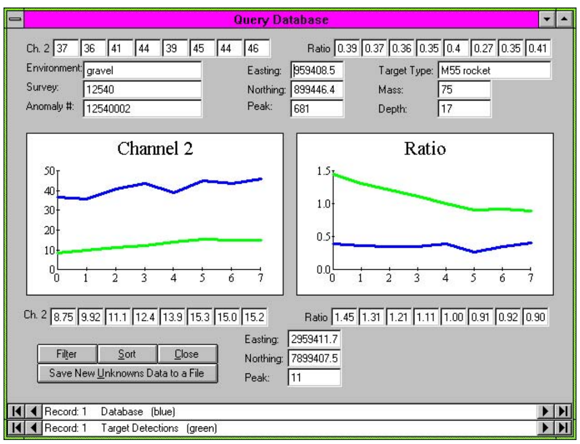
Huntsville Center is developing a computer-based evaluation tool known as the Ordnance and Explosives Knowledge Base (OE-KB). Digital input from a variety of geophysical instruments is combined in OE-KB's data base for subsequent evaluation and interpretation. The goal is automated detection and recognition of buried munitions.

One of the major efforts of Huntsville Center has been to evaluate results of geophysical instruments used at sites containing buried munitions in order to determine which commercial geophysical instruments are capable of collecting the best available digital data set, and then learning how to understand, analyze, and catalogue the data. While it is relatively easy to determine if *something* is buried at a given location, it is quite a different task to successfully predict how deep that something is buried and just what that something might be. A small piece of wire buried a few inches beneath the ground might yield a signal not easily discriminated from a large munition buried several feet. Many of the common analytical methods used for estimating mass and depth of burial yield non-unique solutions and are subject to large errors. Current experience is that predictions of mass and depth should be considered educated guesses rather than statements of fact.



Computer Enhanced Digital Geophysical Data

OE-KB uses artificial-intelligence neural-network techniques to enhance its ordnance-recognition capabilities. The use of sophisticated mathematical algorithms, computerized pattern recognition, and *data-fusion* (the combination and comparison of data-sets from two or more different types of geophysical instruments) help differentiate between munitions and non-munitions and estimate depth of burial.



Knowledge Base Data Screen

Using a variety of geophysical methods, Huntsville Center is collecting geophysical data from a number of sites and adding this data to OE-KB. This improves the understanding of different geophysical instruments' munition detection and recognition capabilities. One goal is to make Huntsville Center's OE-KB data set available to civilian and military organizations involved in the geophysical detection and identification of buried munitions.

Limitations of Geophysical Surveys

Geophysical investigations for buried munitions are seldom 100 per cent effective. In many cases a munition is simply buried too deep or is too small to be detected, or it is constructed of a material difficult to detect. Later, through erosion, frost heave, agricultural activity, or construction, people become exposed to the item. In addition, since the total amount of munitions buried at a site is almost never known, complete recovery cannot be documented. These factors should be considered when designing and implementing a QA/QC program at a munitions investigation and recovery site. The limitations of geophysical investigations must be conveyed to all the stakeholders involved with a site so that there is a common understanding of expectations.

SUMMARY

It is important to understand the capabilities, uses, and limitations of different types of geophysical instruments used for detecting buried munitions. If instruments are used inappropriately then munitions may remain buried that could have been detected, identified and removed. This will result in miscalculation of remaining munitions risk associated with a site, and increase the possibility of a future accident that might have been avoided.

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